



New Millennium Program



The First New Millennium Deep Space Flight



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JANUARY 28, 1997

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Overview System Elements

MISSION

- Thirteen advanced technologies validated via an asteroid flyby/comet flyby “test track” profile
- Asteroid McAuliffe and Comet West-Kohoutek-Ikemura
- Mars “flyby” recently added to mission plan

SPACECRAFT

- Two years required lifetime; four years goal

LAUNCH SERVICES

- Delta 7326
- Provided via NASA GSFC, Orbital Launch Services

GROUND SEGMENT

- Maximum use of JPL multi-mission infrastructure
- Consistent with highly autonomous spacecraft

SCIENCE

- Taken at appropriate times during the mission (cruise and encounters)
- Details to be defined by DS1 Science Team (1997)

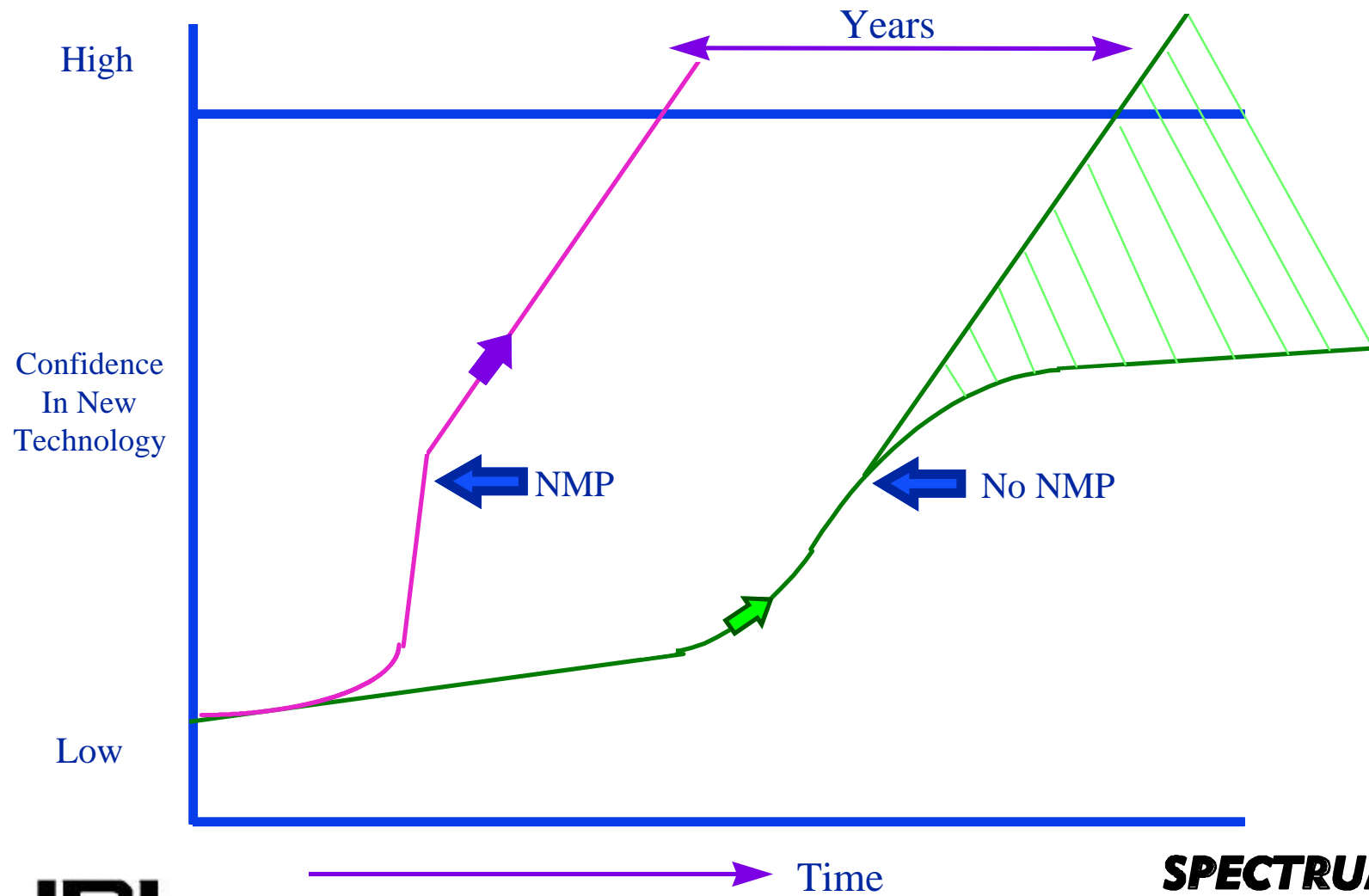




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New Millennium Goal



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Current Status

- Pre-project work started in mid 1995
- Selected Spectrum Astro as full industry partner in September 1995
- Mission go-ahead given by NASA HQ in September 1995
- Completed mission and system Interim Design Concurrence (IDC) Review in December 1995
- Launch vehicle selected in June 1996
- Project plan briefed to NASA HQ in July 1996 - funding and support is solid
- Completed mission and system Detailed Design Concurrence (DDC) and Sage review, September 12, 1996
- Ground segment and S/C hardware detailed design reviews completed 12/96 - Flight S/W autonomy reviews in process
- Working solar cell efficiency concerns
- Integration and test activities “ramping” up





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DS1 Technology Partners

| TECHNOLOGY DESCRIPTION | IPDT | TECHNOLOGY SUPPLIERS | FUNDING SOURCES |
|---|--------|--------------------------------------|-----------------------|
| Ion Propulsion System | N/A | Hughes, Moog, LeRC, JPL | NASA, Moog, Hughes |
| SCARLET Solar Concentrator Array | MAMS | AEC-Able | BMDO, NASA |
| Small Deep Space Transponder | N/A | Motorola | NASA, Motorola |
| Ka-band Solid State Power Amplifier | Comm | Lockheed Martin (LM), JPL | Lockheed Martin, NASA |
| Autonomous Remote Agent Architecture | Auto | CMU, TRW, JPL, ARC | NASA |
| Autonomous Onboard Optical Navigation | Auto | JPL | NASA |
| Beacon Monitor Operations | Auto | JPL, Univ. of Colorado at Boulder | NASA |
| Miniature Imaging Camera Spectrometer | IT&A | SSG, Rockwell, Univ. of Arizona, JPL | NASA, SSG |
| Miniature Ion and Electron Spectrometer | ISIM | SwRI, LANL | NASA, SwRI |
| 3D-Stack Processor | MicroE | SCC, LM, Boeing, TRW, JPL, AF/PL | NASA, AF/PL, industry |
| Low Power Electronics Experiment | MicroE | Georgia Tech., USC, MIT Lincoln Lab | NASA |
| Power Actuation and Switching Module | MicroE | LM, Boeing | NASA, Lockheed Martin |
| Multi-Functional Structures | MAMS | AF/PL, LM | AF/PL, LM |

LEGEND

| | |
|--|--|
| IPDT = Integrated Product Development Team | ISIM = In-Situ Instruments & MEMS |
| IT&A = Instrument Technologies & Architectures | MEMS = Micro-electro Mechanical Systems |
| Auto = Autonomy | MAMS = Modular & Multifunctional Systems |
| Comm = Communications systems | MicroE = Microelectronics Systems |





DS1 Technology Payload

- Solar electric propulsion
 - Provided by NSTAR (NASA SEP Technology Applications and Readiness) Program
 - $2.6 \text{ kW} \Leftrightarrow I_{sp} = 3300 \text{ s}$; throttle in discrete steps to $0.6 \text{ kW} \Leftrightarrow I_{sp} = 2200 \text{ s}$
 - Diagnostics package for E and B, energy and density of electrons and ions, and surface contamination
- Solar concentrator array (SCARLET)
 - Provided by BMDO
 - Arrays of cylindrical Fresnel lenses over strips of $\text{GaInP}_2/\text{GaAs}/\text{Ge}$
 - 2.6 kW at 1 AU BOL
- Miniature integrated camera and imaging spectrometer (MICAS)
 - 2 visible imaging channels
 - IR and UV imaging spectrometers
 - Shared 10-cm primary mirror
 - 7-kg package, no moving parts
- Miniature integrated ion and electron spectrometer (PEPE)
 - Energy and angle analysis for electrons and ions
 - Ion mass analysis
 - Microcalorimeter
 - 5-kg package, no moving parts





DS1 Technology Payload (Cont'd)

- On-board autonomy
 - Remot Agent (RA)
 - Planner/scheduler to generate a set of activities
 - Executive to expand that to a sequence of commands and to monitor their execution
 - Mode identification and reconfiguration
 - Optical navigation (AutoNav)
 - Image processing of asteroids against stellar background
 - Orbit determination
 - Maneuver design
 - Beacon monitor operations (BMOX)
 - Transmit 1 of 4 tones to indicate urgency of request for ground action. For example
 - > No tracking required
 - > Track within 2 weeks
 - > Track within 1 week
 - > Track as soon as possible
- Small deep-space transponder (SDST)
 - X-band receiver, X-band and K_a -band exciters, CDU, TMU, and beacon tone generation
- K_a -band solid state power amplifier (KAPA)
 - 2.5 - 3 W RF, 12.5% - 15% efficiency





DS1 Technology Payload (Cont'd)

- Flight computer using 3-D stacking technologies (TDE)
 - 33 MHz RAD6000-5L
 - 320 MB DRAM in stacked cubes
 - 128 MB nonvolatile memory module
 - Interface, including dual rate 1773 fiber optic communications
- Power actuation and switching module (PASM)
 - Power switch using high-density interconnects with mixed signal ASIC controller
- Low power electronics (LPE)
 - 1 V logic, 0.18 μm feature size
- Multifunctional structure (MFS)
 - Electronics and thermal management combined in one load-bearing structural element





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DS1 Technology Rationale

| Technology | Inner solar system | Outer solar system | Astro-physics | Space physics | Earth science | Why validate in space? | Level of advancement over SOA | Comparison to other new technologies |
|------------------------------------|--------------------|--------------------|---------------|---------------|---------------|--|--|---|
| Solar electric propulsion | + | + | ✓ | ✓ | | End-to-end system test & validation | $10 \times I_{sp}$ of chemical propulsion | Significantly higher I_{sp} & thrust than SEP systems for station-keeping on comm. satellites |
| Solar concentrator array | , | * | , | , | , | End-to-end system test & validation | $2 \times$ reduction in cost; $1.5 \times$ reduction in area | Higher power and higher efficiency than array destroyed with METEOR (on Conestoga launch vehicle) |
| Autonomous navigation | + | + | , | | | End-to-end system test & validation | Eliminates need for ground navigation tracking | No comparable technology |
| 3-D stack computer | , | , | , | , | , | End-to-end system test & validation | $3 \times$ reduction in mass and volume; use of commercial standards (PCI interface) | More capable computer than on SSTI (Lewis), which has only 1 multichip module slice. (DS1 will have 4.) |
| Integrated camera and spectrometer | + | + | | | , | Validation of return of science-quality data | $10 \times$ reduction in cost, mass, and power | No comparable technology |
| Small deep-space transponder | + | + | , | | | Tests new DSN capability; need long range communications | $2 \times$ reduction in mass; $3 \times$ reduction in cost; increased functionality | No new technology in this area in 10 years |

+ = Enabling technology for many missions

, = Enhancing technology for many missions or enabling for some





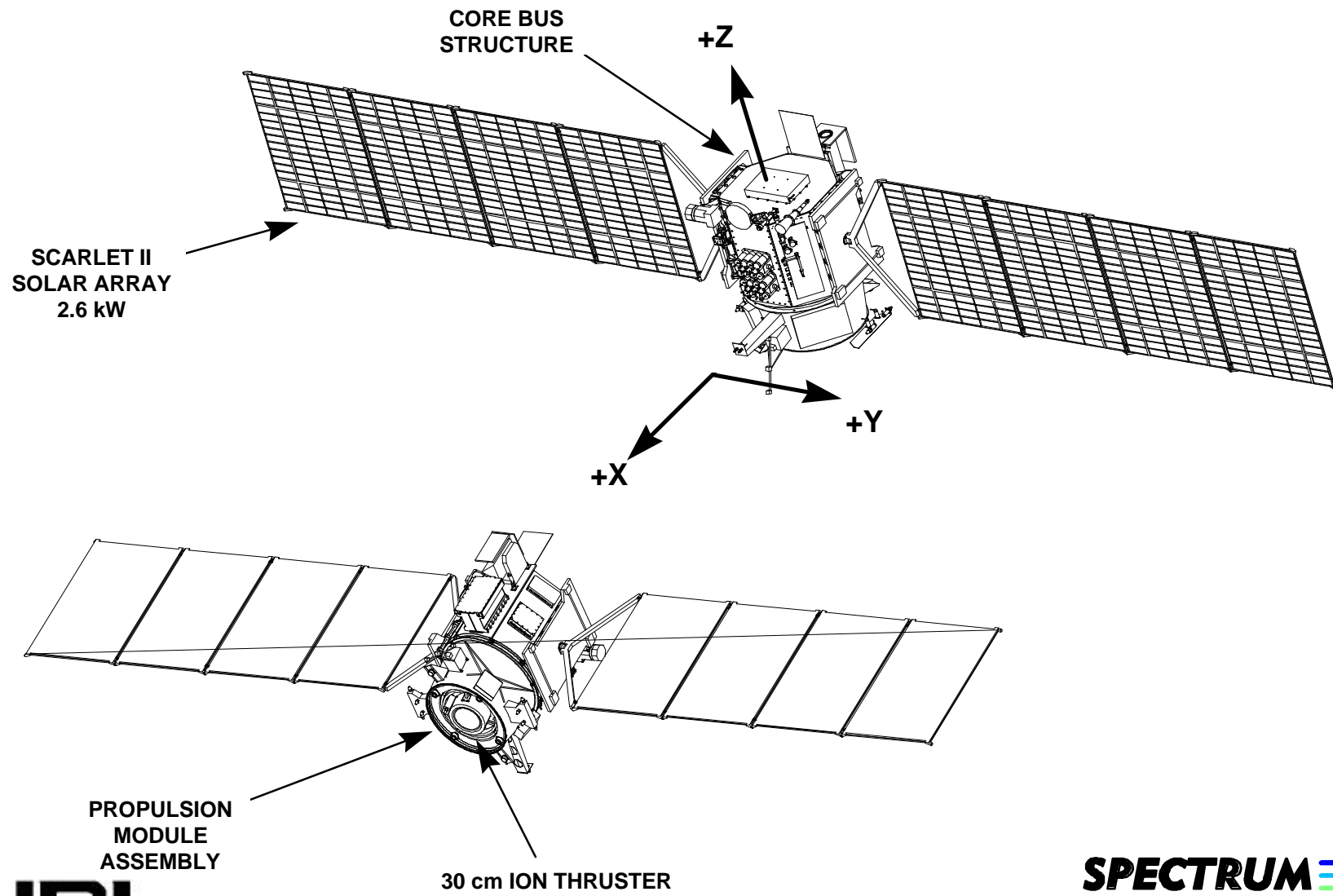
DS1 Technology Rationale (Cont'd)

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|--|--------------------|--------------------|---------------|---------------|---------------|--|---|--|
| Remote agent architecture | + | + | + | ✓ | ✓ | End-to-end system test & validation | 2.5 × reduction in ops cost; 2 × reduction in mission-specific S/W development | No comparable technology |
| Integrated ion and electron spectrometer | , | , | | , | | Tests effects of IPS and provides validation of science-quality data | 5 × reduction in mass; 3 × reduction in power | Comparable performance, lower mass and power than on Cassini; no moving parts. |
| Beacon monitor operations | , | , | | | | End-to-end system test & validation | Eliminates need for routine tracking by large antennas of DSN | No comparable technology |
| Ka-band solid state power amplifier | , | , | | | | Tests new DSN capability; need long range communications | 1.5 × greater dc-to-rf efficiency; 5 × greater data rate than X-band | Higher power, higher efficiency SSPA than on MGS |
| Low power electronics | , | , | , | , | , | End-to-end system test & validation | 50 × reduction in power | Significantly lower power than on Mars Pathfinder |
| Multi-functional structure | , | , | , | , | , | End-to-end system test & validation | 3 × reduction in mass of cabling and electronic packaging | No comparable technology |
| Power actuation & switching module | , | , | , | , | , | End-to-end system test & validation | 20 × reduction in mass and volume; 10 × reduction in power | No comparable technology |





New Millennium Program Spacecraft Configuration



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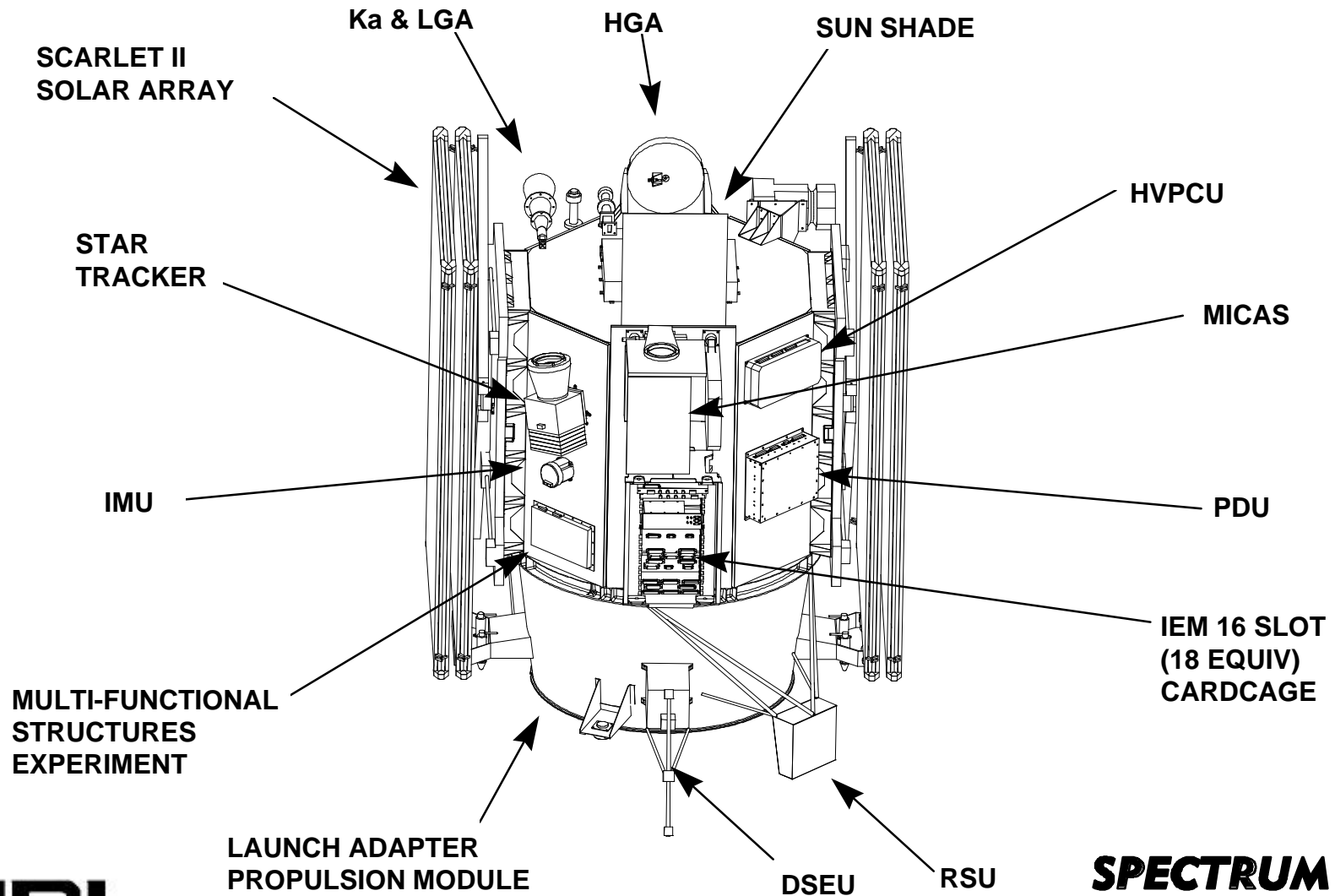
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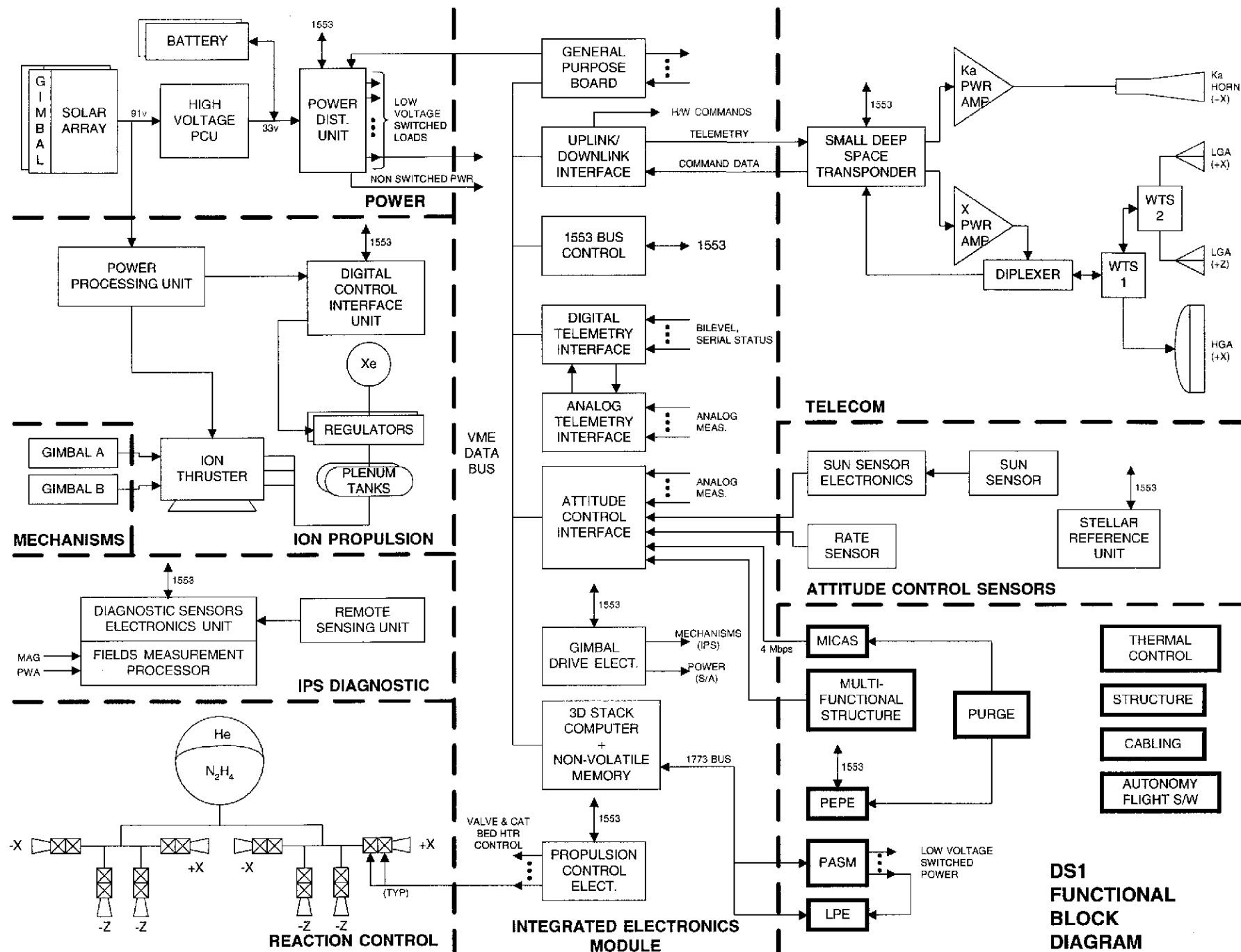


Equipment Arrangement



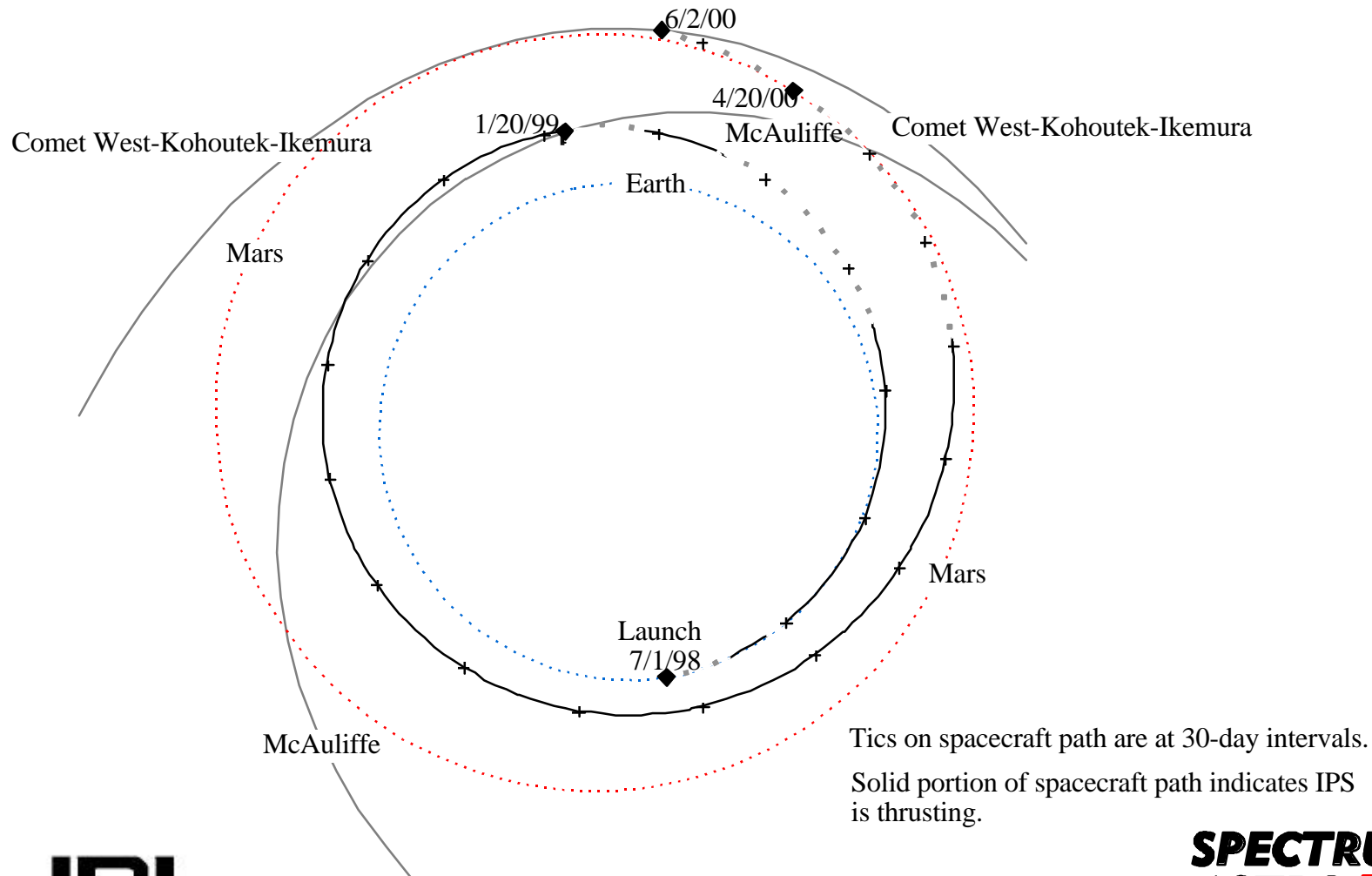
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DS1 McAuliffe/Mars/West-Kohoutek-Ikemura Flyby



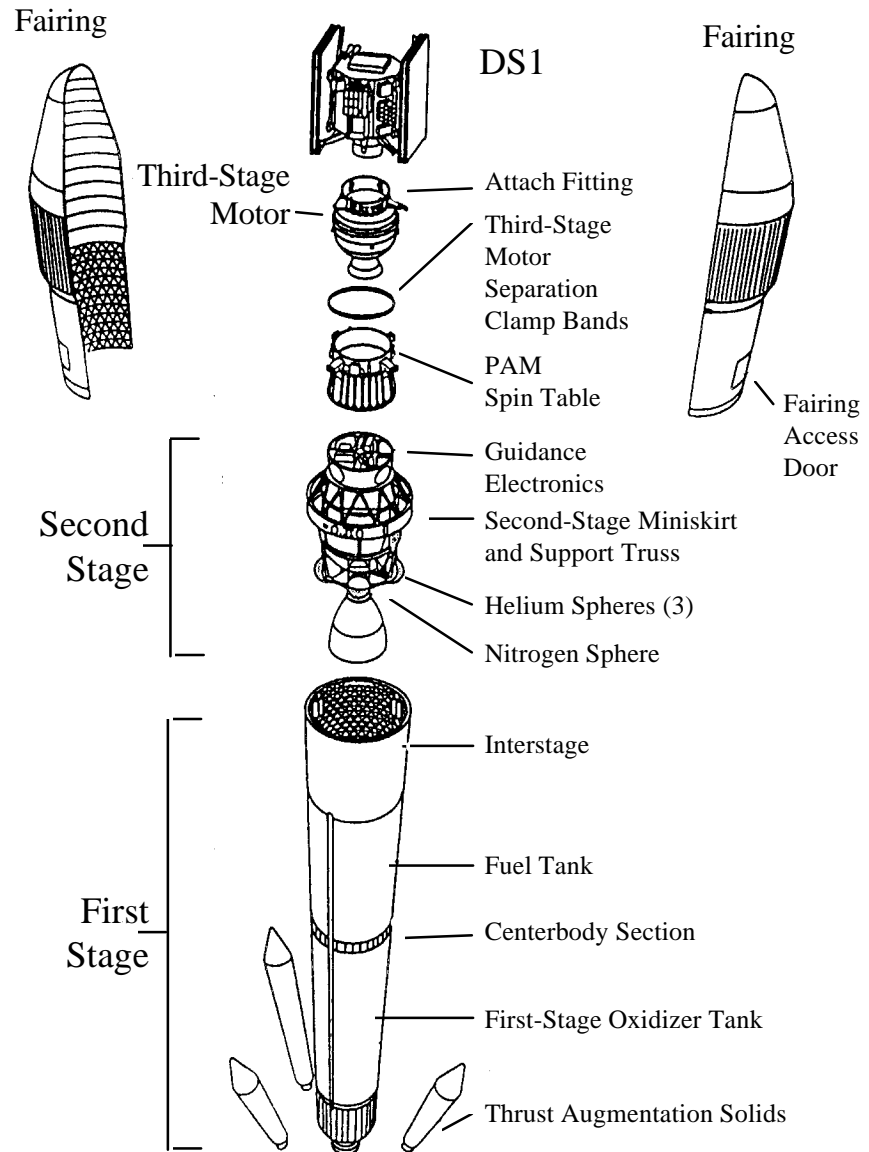
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Launch Vehicle

Delta 7326-9.5

- Injection capability to escape 600 kg (for declination of launch asymptote $< 28.7^\circ$). After allocation for secondaries is withheld, DS1 is allocated 487 kg to $C_3 = 0 \text{ km}^2/\text{s}^2$.
- Launch from Cape Canaveral Air Station.
- First Launch under NASA's Med-Lite contract and the first launch of the Delta 7326.





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QuickTime FICT



QuickTime FICT



QuickTime FICT

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Major Project Milestones

- | | | |
|--|----------------|---|
| a) Project start | October 1995 | ✓ |
| b) Complete DS1 Mission and Systems Interim Design Concurrence (IDC) Review | December 1995 | ✓ |
| c) Complete Sage Review #1 | May 1996 | ✓ |
| d) Complete DS1 Mission and Systems Detailed Design Concurrence (DDC) Review & Sage Review #2 | September 1996 | ✓ |
| e) Start S/C integration at SAI | May 1997 | |
| f) Deliver Partial Bus from SAI to JPL. Commence Assembly, Test and Launch Operations (ATLO) | August 1997 | |
| g) Complete system tests & ship to KSC | April 1998 | |
| h) Launch commitment to NASA | July 1998 | |
| i) End of primary mission | June 2000 | |





Development Approach

- Utilize and improve upon lessons learned from Mars Pathfinder (MPF) and other projects with respect to low cost, rapid development
- Design to cost (project is cost capped) and schedule
 - Capabilities driven mission
- Learn implementation approach from Spectrum Astro (MSTI 1, 2, 3)
- Work closely with JPL re-engineering teams to develop, test and prototype processes
 - Flight system testbed and project design center
 - Video conferencing & electronic documentation
 - Schedule receivable/deliverable system
 - Flight part acquisition
 - “Art-to-Part”
 - Re-useable Electrical GSE
 - Multi-mission low thrust navigation software
 - Partnering with Industry





Development Approach

- Maximize value of DS1 advanced technologies to the extend feasible-within cost cap. Rest of spacecraft procured through Spectrum Astro.
 - Some exceptions: Telecom, Flight harness
 - Use low risk, off-the-shelf hardware
- Maintain healthy cost, schedule, reserves and performance margins
 - Track monthly - take action before it become a problem
- Learn to operate in declining budget environment
 - Requires multiple funding sources
 - Requires projects/government agencies to co-operate more than in the past





IPDT/ Flight Team Lessons Learned

- DS1 technology payload is first class
- Technology team members/leadership outstanding
- Teaming between technology payload team and flight team has been excellent
- Selection process
 - Chaotic
 - Peer review
- Contracting
 - Ensure money flows
 - Teaming
- Lead engineer's boss





DS1 Mission Highlights

- First deep-space technology validation mission
- First use of electric propulsion to go somewhere
- First use of machine intelligence (AI) to control and operate a spacecraft
- First use of autonomous onboard deep-space navigation
- Smallest flyby distance of any solar system body (5 km at asteroid) and closest approach to a comet nucleus (500 km)
- First spacecraft with UV or IR imaging spectrometer to a comet
- First launch in NASA Med-Lite series

